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Evolutionary Game Analysis of Industrial Transfer Dynamics and DUT Development in Military Civilian Sectors

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Abstract – We explore the competitive interaction between military and civilian firms on industrial transfer and Dual-Use Technology (DUT) development employing an evolutionary game theory. This work is intended to examine the effect of some strategic modes (Mix, Spin-In, and Spin-off) on the effort level, income generation and technological advancement. Optimum effort of military and civilian enterprises is analyzed by creating equilibrium conditions while performing the analysis. The study reveals that the Mix mode yields the highest combined effort and revenue for both firms and results in improved performance for both firms than in the other modes. The findings of the simulation study support these outcomes too; the Mix mode accelerates technical advancement more than the other modes; the Spin-In mode is in the middle; and the Spin-Off mode is the slowest. The revenue simulations support these findings where the Mix mode maximizes both personal and overall income for the military and civilian businesses. Therefore, the approach that this research reveals to hold the most effectiveness for the development of DUT, enhancement of industrial transfer and overall economic benefits for both sectors is the Mix mode. These implications are important for policy making involving the fostering of civil-military relations for innovation and technology transfer.

Keywords – Industrial Transfer, Technology Transfer, Evolutionary Game Analysis, Civil-Military Integration, Dual-Use Technology Development, Military Technology.

I. INTRODUCTION

Industrial transfer [1] is defined as the migration of some industries from one location to another; it therefore encompasses both international and regional shifts. This particular type of transfer is commonly considered as one of the key factors towards a sustainable economic and regional development [2]. Some resource and economic factors include; limited availability of land resources and rising cost of labor which makes some industries that use these resources to be relocated from the developed to underdeveloped countries during an industrial transfer process [3]. Since China's reform and opening up policy in 1978, the coastal region economies have been developed with the support of national policies. They have successfully established their own geographical advantages and a favorable foreign investment climate. However, a range of issues have emerged in these coastal regions, including inadequate development progress and diminishing labor cost benefits [4]. In contrast, the western area has advantages in terms of land, labor, and policies [5]. Consequently, local governments actively promote the progressive relocation of businesses from the eastern region to the central and western regions, while simultaneously optimizing its industrial structure [6].

Industrial transfer is crucial for stimulating economic development in the interior areas, executing economic restructuring on the coast, and transforming the national competitive advantage of the People's Republic of China (PRC) [7]. For the coastal region, the movement of labor-intensive, low-end manufacturing into the interior creates space for higher-end production and tertiary economic activity [8]. This approach is referred to by Chinese officials as "emptying the cage to change the bird" (tenglong huanniao). The internal relocation of sectors in inland economies results in an unparalleled influx of investment and creates new prospects for development [9]. If the PRC establishes a well-organized division of labor based on regional distinct advantages, it might gain a significant advantage over other national rivals. Indeed, very few countries can claim to have the very lowest to greatest levels of output inside a single market. While the PRC operates on a hierarchical structure, the central leadership lacks the authority to direct provincial governments to specialize in certain industrial sectors [10]. Neither can state authorities enforce the relocation of privately-owned and foreign-owned enterprises to specified areas. Therefore far, the transfer of industries inside the PRC has mostly been a decentralized and market-oriented process that opposes meticulous state planning, whether by central or local administrative bodies.

In the context of technological transfer between civilian and military uses, the phrase 'dual-use' was first used. A Dual-Use Technology (DUT) is a technology that is produced and employed by both the military or space sector and the civilian sector. In other words, it is technology that has uses in both military and commercial domains. Sánchez-Cobaleda [11] clarified that there are instances where the word dual-use coincides with the term spin-off. In their concise analysis of the dual-use idea, Rajagopalan and Stroikos [12] also acknowledge the fortuitous inclusion of these concepts. Brenneis [13] and Camacho [14] contended that dual-use encompasses the long-term industrial benefits of research and development activities that extend beyond the original goals. DUT [15, 16, 17] may be interpreted in two ways: military technology serving as a basis for civilian innovation (spin-off) or vice versa (spin-in). Although there is evident usage of civilian technology for military reasons, the primary emphasis has been on the transfer of military breakthroughs to civilian use.

The phenomena of dual use technology exemplify the unique characteristics of postmodern understanding of a human being as an individual who exercise agency in choosing between natural and artificial, life and death, and progress and stasis. Moreover, it demonstrates an understanding of a human being as an individual seeking and expanding the structures of their own life, creating a whole new system by building upon current systems. Capps et al. [18] suggests that a comprehensive understanding of the anthropogenic implications of biotechnologies (and technologies in general) may be achieved by addressing three fundamental inquiries: (1) the existence of human beings; (2) the nature of human beings; and (3) the complexity of the human involvement [19]. Tywoniak et al. [20] observes that advanced technologies have the potential to be perilous as they may enable us to exhaust the humanistic aspect of life or jeopardize the survival, fundamental nature, or population of humanity.

Originally derived from the field of ecological biology, Evolutionary Game Theory (EGT) distinguishes itself from classical game theory by placing more emphasis on the stability and dynamics of the tactics used by the whole population, rather than only on the attribute of equilibrium. The EGT model has found extensive use in modeling user behaviors in image processing, communication and networking, congestion management, dynamic spectrum access, cooperative peer-to-peer (P2P) streaming, and cooperative sensing. Skarding, Gabrys, and Musial [21] have shown that evolutionary games are a very effective method for modeling the dynamic social engagements among individuals within a network. EGT is a precise method for analyzing the process by which a group of players reach a more stabilized equilibrium after strategic engagement. The Evolutionarily Stochastic System (ESS) is a specific equilibrium approach identified as such. An evolutionary game with N players is considered an ESS if and only if a strategy profile an $a^*(a_1^*, \dots, a_N^*)$, where $a_1^* \in x$ and x is the action space, $\forall a \neq a^*$, a^* follows Eq. (1) and (2):

$$U_i(a_i, a_{-i}^*) \leq U_i(a_i^*, a_{-i}^*), \tag{1}$$

$$U_i(a_i, a_{-i}) \leq U_i(a_i^*, a_{-i})\ U_i(a_i, a_{-i}^*) \leq U_i(a_i^*, a_{-i}^*), \tag{2}$$

Here, U_i represents the application of i, whereas a_{-i} represents the approaches of the players except i. The initial condition under consideration is the Nash equilibrium (NE) state [22], whereas the subsequent condition ensures the constancy of the approach. Furthermore, it is evident that a stringent NE is always an ESS. Assuming that all players embrace the ESS, it follows that no mutant approach may infiltrate the population due to the effects of natural selection. Although a minority of participants may lack rationality and choose out-of-equilibrium schemes, the ESS remains a locally stable condition. We will examine an evolutionary game characterized by m strategies denoted as $X = \{1, 2, \dots, m\}$. A utility matrix, U, is a $m \times m$ matrix where u_{ij} represent the utility assigned to option i compared to j. The fraction of population i is denoted as p_i, where $t(i)$ is equal to $\sum_{i=1}^{m} p_i = 1$. The fitness parameter of i is defined as $f_i = \sum_{j=1}^{m} p_j u_{ij}$. The average fitness of the whole population may be quantified as $\emptyset = \sum_{i=1}^{m} p_i f_i$. The Wright-Fisher model is often used to enable players to congregate to the ESS. In this model, the method update equation representing each player may be expressed as Eq. (3):

$$p_i(t+1) = \frac{p_i(t) f_i(t)}{\emptyset(t)} \tag{3}$$

This research paper explores the dynamics of industrial transfer and DUT development between civilian and military firms through an evolutionary game-theoretic framework. It examines how different strategic modes impact effort optimization, revenue generation, and technology advancement. By establishing equilibrium conditions and conducting simulations, the study reveals that the Mix mode offers the highest collective effort, revenue, and technological growth, making it the most effective strategy for fostering collaboration and maximizing economic returns in military-civilian partnerships. The remaining sections of this research have been organized in the following manner: Section II describes the design of the model employed in this research. Section III provides detailed equilibrium, simulation, and revenue analyses.

In Section IV, a detailed discussion of the findings, which includes equilibrium results (optimal effort level, optimal revenue, and DUT development), and simulation results (generic simulation), has been provided. Lastly Section V concludes that the Mix mode is the most effective method for DUT development, enhancing industry transfer, and enhancing total economic benefits.

II. MODEL DESIGN

Technological manufacturing for military and civilian purposes takes place in distinct market ecosystems [23]. The military technology industry has extended periods of experimentation and production, characterized by significant technological requirements and expenses within a market that operates independently and autonomously [24]. In the literature on international relations theory, the replication of military technology assumes a vital but undervalued position. Internal balance, for example, often involves replicating foreign technology [25]. However, Derian and Wendt [26] in the field of international relations have not examined the specific circumstances and reasons behind the success of attempts to replicate foreign military systems. Instead, they have presumed that the deliberate intents or motivations of states to mimic would automatically result in success. Conversely, the civilian sector operates under a dynamic and rapidly evolving macroeconomic context, necessitating reduced pricing, enhanced qualifications, and expanded product capabilities to appeal to customers. Thus, when civilian and military firms join one other's market, they may encounter intricate cooperative and competitive dynamics throughout the conversion of DUT.

Civil-Military Integration (CMI) [27, 28] is a comprehensive movement that consist of many policy measures. Originally characterized as the amalgamation of the Industrial Base and Defense Technology and the Commercial Technological Base into a cohesive Industrial Base and National Technology, the integration movement of civil military has progressed from one administration to another [29]. An integral part of the CMI movement was 1997 DRI (Defense Reform Initiative) [30] and the subsequent Business Affairs Revolution [31]. The objective of both these initiatives was to integrate the most effective commercial business activities from private sectors into the military control and export strategy of the Department of military [32].

For the purpose of streamlining the transfer of DUT between economics and defense innovation frameworks in Civil-Military Integration (CMI), we categorize them into two economic segments: military civilian (C) and enterprises (M) enterprises (C). The participating segments are assumed to be completely rational, possess complete knowledge, and want to maximize their profits [33]. The ownership interest and technical confidentiality in contact to DUT may influence the intents of civilian and military firms, who serve as both the technology supplier and receiver [34]. From a conventional security standpoint, the dual-use security problem expands the concerns of policy makers over an adversary's defensive or offensive intents to include the apprehension of inherently dangerous civil technology. There is uncertainty among policy makers over the potential detrimental intents of the opponents in employing the technology [35]. However, the possibility of their exploitation or modification of the technology for detrimental intentions, even in the long run, generates uncertainty and may motivate policymakers to implement safeguards to counter the menace. Like the classic security problem, these measures have the potential to shape the behavior of an adversary, prompting them to obtain military capabilities or even to use the DUT for military purposes.

Due to China's historically unique civilian and defense innovation regimes, the difference between civilian and military technology is based on institutional factors rather than inherent attributes [36]. These disparities have the potential to result in "lock-in" stage of the path-based process for military and civil enterprises, therefore limiting their availability for technology transfer [37]. Lock-in refers to a conceptual model, which describes how particular technological advancements, as they continue to evolve alongside political, cultural, institution, and social systems, may become more resistant to change [38]. This resistance acts as a barrier, limiting the potential for the growth of substitute socio-technical configurations that may be superior or more environmentally and socially desirable. The possible adverse consequences of technology lock-in, also known as entrapment or entrenchment, include a range of environmental and societal issues including climate change, ecological deterioration, resource exhaustion, pollution, health concerns, and social breakdowns [39]. Typically, these effects are only identified after the system has already been firmly established. Observations indicate that the dominance of a certain technology is likely to result in the exclusion of others, leading to a decline in variety. This erosion may occur either by coincidence or intentionally by proponents of certain technologies [40]. Therefore, it has been proposed that one mechanism to maintain flexibility (and prevent harmful lock-in) is via preserving variety.

Both military and civilian organizations must allocate extra resources and funding towards communication and external management [41]. The effort level of technology conversion for military firms at time t is denoted as $E_M(t)$, whereas that for civilian firms in DUT transfer is denoted as $E_C(t)$. Technology conversion costs for civilian and military firms may be represented by the functional expression $c_M(E_M(t), t)$ and $c_C(E_C(t), t)$, correspondingly, which utilizes quadratic equations to account for the convexity of effort level and costs at time t. Take into account Eq. (4):

$$c_M(E_M(t), t) = \frac{\mu M}{2} E_M(t)^2 c_C(E_C(t), t) = \frac{\mu C}{2} E_C(t)^2 \tag{4}$$

Let μM and μC represent the cost coefficient of civilian and military enterprise at time t, respectively. The CMI will facilitate the transfer of DUT via communication and collaboration between civilian and military organizations. The ongoing integration of dual-use technologies via external acquisition and internal transformation will consistently enhance the overall technological level development [42]. Dual-use technologies undergo evolution when they are transferred from one organization to another. The supplier may adapt the technology at the output based on the circumstances of the other party. Analysis by Mowery [43], a U.S. national defense economist, reveals that a minimum of 40 percent of effective military technology contribute to enhancing the economic welfare of individuals. More precisely, military technology has the capability to improve a nation's security and the aggregate national economy [44]. By integrating military technology into private industries, nations not only impart military innovations or inventions to civilian livelihoods that generate revenue, but also contribute to the advancement of technology in private industries, which reciprocally play a crucial role in the development of national defense.

During the process of "learning by acting," the receiver integrates the novel technology in a manner that aligns with the requirements of the facilities and researchers [45]. Technological advancement is fundamentally driven by the conversion efforts of military and civilian organizations [46]. Simulations are enhancing our capacity to evaluate extensive military operations, including the impact of command and control, various operational ideas, and novel force formations and military architectures. Simulations have significantly advanced the integration of technology and training to establish environments where individual soldiers, weapons, and combat units (including temporary formations) can be trained and assessed against enemy forces in conditions that surpass field training and approximate reality [47]. The use of electronics, ranging from aviation simulators to interactive wargames, is essential for the simulation of various settings. Simulations also facilitate the identification and resolution of command, control, and intelligence issues prior to real military actions, therefore enhancing our capacity to promptly adapt plans while information is still up-to-date and allows for its exploitation [48]. Prominently, simulations serve as the instructional tool that enables us to acquire expertise in the integration of different systems and networks in order to achieve their maximum capabilities. The degree of dual-use technologies, denoted as $K(t)$, is determined by stochastic differential equations in Eq. (5):

$$\begin{cases} dK(t) = [\alpha E_M(t) + \beta E_C(t) - \delta K(t)]dt + \varepsilon\big(K(t)\big)dz(t) \\ K(0) = K_0 \geq 0 \end{cases} \tag{5}$$

The decreasing DUT coefficient is denoted as $\delta \in (0, 1]$; and technological innovation capability (TIC) coefficient of civilian and military firms on the advancement of technical level are represented by; $z(t)$ and $\varepsilon K(t)$, respectively. The initial technology level is denoted as K_0. $K(t)$ is inherently a rising function characterized by declining marginal returns. Given constant other parameters, the DUT development element $K(t)$ is constrained. The demand element used in the conversion of DUT consists of two elements: economic demand and national demand. Eq. (6) describes the demand element, where λ refers to the coefficient for civilian and military firms of local defense demand and θ refers to the economic demand coefficient.

$$Q(t) = \lambda[E_M(t) + E_C(t)] + (\lambda + \theta)K(t) \tag{6}$$

III. EQUILIBRIUM AND SIMULATION ANALYSIS

Equilibrium Analysis

In this section, we analyze the equilibrium dynamics of the system under study, focusing on the interaction between the government, civilian firms, and military firms. To capture the competitive behaviors of these actors within the evolutionary game framework, we model the interaction using differential equations representing the rates of change in effort levels, technology development, and revenues across the different players. Let the variables E_M, E_C, and E_G denote the effort levels of the military, civilian, and government sectors, respectively. The following system of equations is intended to define an equilibrium state which arises when each actor employs his suboptimal strategy. We begin by specifying the military and civilian sectors' utility functions. Let U_M be the utility for the military firm as a function of its effort and the technology transfer rate α\alphaα provided by the government and let U_C be the utility of the civilian firm as a function of its effort and the technological spillover β from the military as given in Equation: (7) and (8):

$$U_M(E_M, E_C, \alpha) = \frac{E_M^2}{2} - \alpha E_M E_C + R_M(E_M) \tag{7}$$

$$U_C(E_C, E_M, \beta) = \frac{E_C^2}{2} - \beta E_C E_M + R_C(E_C) \tag{8}$$

where $R_M(E_M)$ and $R_C(E_C)$ stands for the particular revenue elements of civilian and military or military firms. By applying the first-order conditions to these utility functions, we derive the optimal effort levels for both the civilian and military firms in equilibrium, as shown in Eq. (9) and (10):

$$\frac{\partial U_M}{\partial E_M} = E_M - \alpha E_C + \frac{\partial R_M}{\partial E_M} = 0 \tag{9}$$

$$\frac{\partial U_C}{\partial E_C} = E_C - \beta E_M + \frac{\partial R_C}{\partial E_C} = 0 \tag{10}$$

Solving these equations for the optimal effort levels E_M^* and E_C^*, we obtain Eq. (11) and (12):

$$E_M^* = \frac{\alpha E_C + R'_M}{1-\alpha^2} \tag{11}$$
$$E_C^* = \frac{\beta E_M + R'_C}{1-\beta^2} \tag{12}$$

Eq. (7) through (12) stand for the Nash equilibrium effort levels of the military and civilian firms under symmetric competition.

Simulation Analysis

In the simulation phase, we look at how effort levels and technology change with time as the organization evolves. Let $K(t)$ denote the development level of the DUT at time t, which has been developed through concerted efforts of government, military and civil society. The growth of DUT [49] is modeled using the following differential equation in Eq. (13):

$$\frac{dK(t)}{dt} = \gamma_M E_M(t) + \gamma_C E_C(t) + \gamma_G E_G(t) - \delta K(t) \tag{13}$$

where γ_M, γ_C, and γ_G stand for the military, civilian and governmental technology contributions respectively and δ for the rate of technological obsolescence. Assuming the initial condition $K(0) = K_0$, we solve this equation to obtain the time evolution of $K(t)$ in Eq. (14):

$$K(t) = \frac{\gamma_M E_M + \gamma_C E_C + \gamma_G E_G}{\delta}\left(1 - e^{-\delta t}\right) + K_0 e^{-\delta t} \tag{14}$$

This equation indicate that the technology development level rises up with time and converges to the steady state value of $\frac{\gamma_M E_M + \gamma_C E_C + \gamma_G E_G}{\delta}$ when t tends to infinity. To check on the stability of the equilibrium [50], we incorporate a stochastic term that captures random shocks in the effort levels and technology contributions. Let σ_M, σ_C, and σ_G represent the variance in the efforts of the military, civilian, and government sectors, respectively. The variance of the technology level $D[K(t)]$ is given by Eq. (15):

$$D[K(t)] = \frac{\sigma_M^2 + \sigma_C^2 + \sigma_G^2}{2\delta^2}\left(1 - e^{-2\delta t}\right) \tag{15}$$

As $t \to \infty$, the variance of the technology level converges to Eq. (16):

$$\lim_{t\to\infty} D[K(t)] = \frac{\sigma_M^2 + \sigma_C^2 + \sigma_G^2}{2\delta^2} \tag{16}$$

Thus, the stability of the technology development process is determined by the variance in the efforts of the different sectors, with higher variance leading to greater instability in the technology level over time [51].

Revenue Analysis

The revenues of the military and civilian sectors are modelled as functions of their effort levels and the technology development level $K(t)$. Let the revenue functions for the civilian and military firms be given by Eq. (17) and (18):

$$R_M\big(E_M, K(t)\big) = r_M E_M K(t) \tag{17}$$
$$R_C\big(E_C, K(t)\big) = r_C E_C K(t) \tag{18}$$

where r_M and r_C are the revenue coefficients for the military and civilian sectors, respectively. Substituting the expression for $K(t)$ into these revenue functions, we obtain the time-dependent revenues in Eq. (19) and (20):

$$R_M(t) = r_M E_M\left[\frac{\gamma_M E_M + \gamma_C E_C + \gamma_G E_G}{\delta}\left(1 - e^{-\delta t}\right) + K_0 e^{-\delta t}\right] \tag{19}$$
$$R_C(t) = r_C E_C\left[\frac{\gamma_M E_M + \gamma_C E_C + \gamma_G E_G}{\delta}\left(1 - e^{-\delta t}\right) + K_0 e^{-\delta t}\right] \tag{20}$$

At steady state, the revenues for the military and civilian firms converge to Eq. (21) and (22):

$$\lim_{t\to\infty} R_M(t) = r_M E_M \frac{\gamma_M E_M + \gamma_C E_C + \gamma_G E_G}{\delta} \tag{21}$$
$$\lim_{t\to\infty} R_C(t) = r_C E_C \frac{\gamma_M E_M + \gamma_C E_C + \gamma_G E_G}{\delta} \tag{22}$$

These results indicate that the total revenue is maximized when the efforts of the military, civilian, and government sectors are coordinated to enhance DUT development.

IV. RESULTS AND DISCUSSION

Equilibrium Results

Optimal Effort Level

The mathematical modeling of DUT conversions [52] between the civilian and military sectors in all three frameworks, as shown in Eq. (23), (24), (25), and (26), allows us to conduct a comparative examination of the equilibrium outcomes of the optimal effort levels.

$$E_M^C - E_M^S = 0 \tag{23}$$

$$E_M^C - E_M^S = \frac{\pi[[\lambda(\rho+\delta)+\alpha(\lambda+\theta)]]}{\mu_M(\rho+\delta)} \tag{24}$$

$$E_C^S - E_C^N = \frac{(2-3\pi)[\lambda(\rho+\delta)+\beta(\lambda+0)]}{2\mu_C(\rho+\delta)} = \frac{(2-\pi)[\lambda(\rho+\delta)+\beta(\lambda+0)]}{2\mu_C(\rho+\delta)} \times \frac{2-3\pi}{2-\pi} = E_C^S \times \eta^* > 0 \tag{25}$$

$$E_C^C - E_C^S = \frac{\pi[[\lambda(\rho+\delta)+\beta(\lambda+\theta)]]}{2\mu_C(\rho+\delta)} \tag{26}$$

Based on the equation $0 < \pi < \frac{2}{3}$, we may derive the terms $E_M^C > E_M^S = E_M^N$ and $E_C^C > E_C^S > E_C^N$. The both civilian and military firms get the maximum degree of effort in the mixed manner. In both spin-in and spin-off modes, the military firm exhibits an equivalent amount of effort. The degree of effort applied by the civilian force is enhanced during spin-in operations as opposed to spin-off operations [53]. Observably, the level of enhancement is equivalent to the optimal subsidies provided by the civilian and military firm [54]. This suggests that subsidies serve as an incentive strategy, which motivates the civilian firm to exert more technology transfer effort.

Optimal Revenue

The equilibrium findings of spin-in strategy, based on Eq. (27), (28), (29), and (30), indicate that the DUT conversion optimum revenue is superior to that of spin-off strategy for both sectors.

$$V_M^S - V_M^N = \frac{(2-3\pi)^2[\lambda(\rho+\delta)+\beta(\lambda+\theta)]^2}{8\mu_C(\rho+\delta)^2\rho} \tag{27}$$

$$V_C^S - V_C^N = \frac{\pi(2-3\pi)[\lambda(\rho+\delta)+\beta(\lambda+\theta)]}{4\mu_C(\rho+\delta)^2\rho} \tag{28}$$

$$V^C - V^S = \frac{\pi^2[\lambda(\rho+\delta)+\alpha(\lambda+\theta)]^2}{2\mu_M(\rho+\delta)^2\rho} + \frac{\pi^2[\lambda(\rho+\delta)+\beta(\lambda+\theta)]^2}{2\mu_C(\rho+\delta)^2\rho} \tag{29}$$

$$V^S - V^N = \frac{(2-\pi)(2-3\pi)[\lambda(\rho+\delta)+\beta(\lambda+\theta)]^2}{8\mu_C(\rho+\delta)^2\rho} > 0 \tag{30}$$

The order of total income, as determined by $0 < \pi < \frac{2}{3}$, is $V^C > V^S > V^N$. This suggests that the optimal outcome may be attained when military and civilian organizations collaborate to carry out the directed DUT conversion [55]. Moreover, the model in spin-in mode, when subjected to the Stackelberg equilibrium state, exhibits the second-greatest payoff.

DUT Development

Analyzing the anticipated and observed changes in the level of DUT enhancement in the three modes enables the stability assessment of technological progress during conversion [56]. The procedure of comparison is as shown in Eq. (31), and (32):

$$E[K^S(t)] - E[K^N(t)] = \frac{1}{\delta}\left(1-e^{-\delta t}\right)(\Omega^S - \Omega^N) > 0 \tag{31}$$

$$\lim_{t\to\infty} E[K^S(t)] - \lim_{t\to\infty} E[K^N(t)] = \frac{1}{\delta}(\Omega^S - \Omega^N) > 0 \tag{32}$$

Similarly, we can get (33), (34), (35), and (36):

$$E[K^C(t)] - E[K^S(t)] = \frac{1}{\delta}\left(1-e^{-\delta t}\right)(\Omega^C - \Omega^S) > 0 \tag{33}$$

$$\lim_{t\to\infty} E[K^C(t)] - \lim_{t\to\infty} E[K^S(t)] = \frac{1}{\delta}(\Omega^C - \Omega^S) > 0 \tag{34}$$

$$\lim_{t\to\infty} D[K^S(t)] - \lim_{t\to\infty} D[K^N(t)] = \frac{\varepsilon^2}{2\delta^2}(\Omega^S - \Omega^N) > 0 \tag{35}$$

$$D[K^S(t)] - D[K^N(t)] = \frac{\varepsilon^2\left(1-2e^{-\delta t}+e^{-2\delta t}\right)}{2\delta^2}(\Omega^S - \Omega^N) \tag{36}$$

The first derivative of the equation $1 - 2e^{-\delta t} + e^{-2\delta t}$ is positive for all values of $t \,\epsilon\, (0, \infty)$. $1 - 2e^{-\delta t} + e^{-2\delta t}$ may be derived by the t-0 transformation, and subsequently, $D[K^C(t)] - D[K^S(t)]$ can be recovered. By a similar process, one may get $D[K^C(t)] - D[K^S(t)]$, in consideration to Eq. (37):

$$\begin{cases} E[K^C(t)] > E[K^S(t)] > E[K^N(t)], \lim\limits_{t\to\infty} E[K^C(t)] >> \lim\limits_{t\to\infty} E[K^S(t)] > \lim\limits_{t\to\infty} E[K^N(t)] \\ D[K^C(t)] > D[K^S(t)] > D[K^N(t)], \lim\limits_{t\to\infty} D[K^C(t)] > \lim\limits_{t\to\infty} D[K^S(t)] > \lim\limits_{t\to\infty} D[K^N(t)] \end{cases} \tag{37}$$

Consequently, the mix mode has a higher propensity for the development of DUT compared to the other 2 modes, with spin-in mode following closely behind [57]. The more advanced DUT becomes, the lower stability level attained by the sectors. Collaborative advancement of DUT by the civilian and military sectors exposes them to increased risk and unpredictable interference elements [58]. These findings demonstrate that the progress and stability of DUT development are greatly impacted by the conversion method. Within a collaborative setting, both military and civilian organizations together make choices aimed at optimizing the whole system [59]. This optimization aims to reduce the conversion threshold, enhance the efficacy of technological innovations, and eventually enhance the overall benefits. Hence, the mix mode may achieve Pareto optimality via the optimization of efforts, income, and technological development [60].

Simulation Results

To demonstrate the hypothetical findings, we performed an arithmetical investigation. In **Table 1**, the values of the parameters are indicated. **Table 2** shows the outcomes for each of the three game models, taking into account the effort put in by both military and civilian players as well as each ideal income level.

Table 1. Customized Parameter Startup Configuration

Notation	α	β	ρ	δ	λ	θ	μ_M	μ_C	π	η
Initialization Set-Ups	0.79	0.59	0.94	0.09	0.69	0.59	0.49	0.49	0.49	0.32

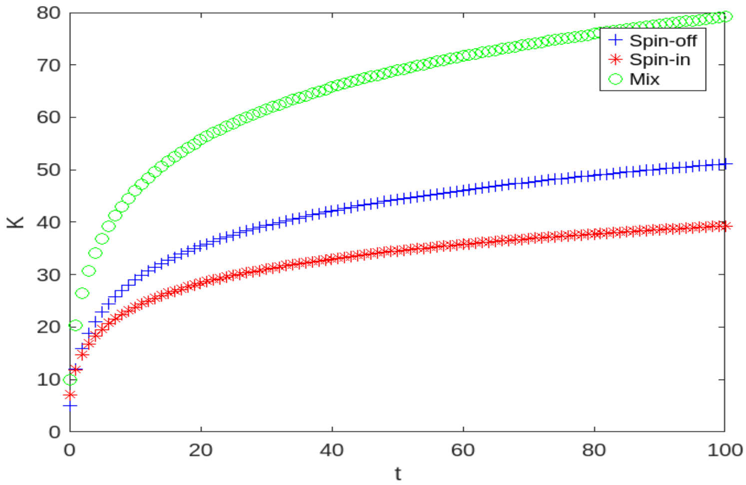

Fig 1. The Degree of Knowledge Acquisition Across the Three Modalities

An analysis of the variations between the civilian and military firm in the scenarios of mix, spin-in, and spin-off modes may be conducted by viewing **Table 2**. The effort level of the firms was progressively enhanced by the 3 approaches. Such is especially true for the civilian firm; the money generated by civilians exceeded that of military participation in all scenarios. In addition, the overall cost reached its peak when the firm opted for the spin-in approach.

Table 2. Comparative Analysis of The Outcomes for the 3 Game Scenarios

	Spin-In	**Spin-Off**	**Mix**
E_M	1.69	1.69	3.38
E_C	2.54	1.44	2.89
V_M	0.62 K + 2.08	0.62 K + 1.85	0.62 K + 2.14
V_C	0.62 K + 2.32	0.62 K + 2.05	0.62 K + 2.14
V	1.24 K + 4.31	1.24 K + 3.9	1.24 K + 4.27

DUT Development in 3 Modes

Equation (50) states that the growth of DUT varies and improves depending on the sequence of mix, spin-in, and spin-off techniques. This study assessed simulations of technological advancement throughout time in three different differential games, as seen in **Fig 1**. The DUT's steady-state development was found to be in accordance with the model's derivation. DUT development began at a comparable stage; subsequently, the pace of technical advancement shifted towards differentiation, and ultimately, reached a stable condition [61]. The mix mode has the highest growth rate, which is twice that of spin-off, and requires the same measurement of time to transition to a stable state compared to the other two modes. Gradually, technology advancement converges to a stable condition when mix exhibits the greatest level of technological advancement, followed by spin-in transformation [62]. Spin-off has the least level of growth.

Revenue by user and overall, in 3 Modes

Based on Equations (27) and (28), the costs for both military and civilian enterprises, as well as the overall revenue, exhibited consistency with simulation, as seen in **Fig 2**. In due course, the advantages for both civilian and military organizations expand and eventually stabilize. The mixing strategy is the most advantageous decision to increase revenue for both civilian and military firms, considering the total returns [63]. Furthermore, these changes were in line with the expansion of DUT. All the three CMI models demonstrate a significant contribution to the growth of profits for both firms. Furthermore, there exists a favorable association between the rise in earnings and the level of technical advancement.

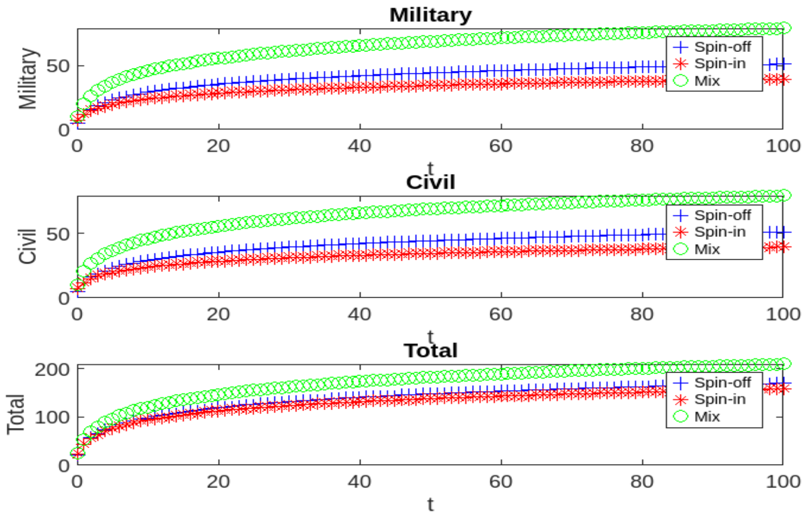

Fig 2. (Top) Temporal Progression of Military Income; (Middle) Temporal Progression of Civilian Revenue; (Bottom) Temporal Progression of Overall Revenue

Comparative Analysis of Revenue between Civil and Military Firms

Both civilian and military companies have enhanced profitability. Nevertheless, there exists a disparity in the profits of the firms within a similar model, as seen in **Fig 3.** Spin-off results in a near convergence of revenue trends between the civilian and military firms, with the military firm generating somewhat lower profits than the civilian firm [64]. This observation implies that the integration of military technology into the civilian firm has a comparable stimulating impact on the growth of revenue for both civilian and military sector businesses. The income generated by spin-in operations is far more than that generated by spin-off operations. Moreover, the profit margin of the military firm is much larger than that of the civilian firm [65]. The introduction of civilian innovation into military products marketplace not only alleviates the strain on the research and development and manufacturing of the military sector but also strengthens the dynamism of the military market [66]. In this research, the earnings patterns for military and civilian firms are similarly similar due to the same setting of distribution coefficients.

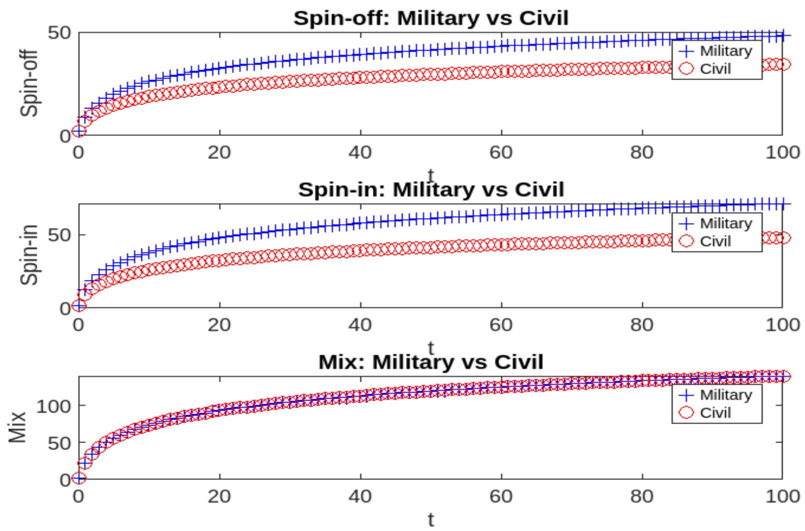

Fig 3. Revenue from the Civilian and Military Sector In (Top) Spin-Off, (Middle) Spin-In, And (Bottom) Mix

V. CONCLUSION

We underscore the effectiveness of collaborative strategies between civilian and military firms in DUT conversion and industrial transfer. Through comprehensive equilibrium and simulation analysis, it has been demonstrated that the Mix mode, where both military and civilian entities cooperate, yields the highest levels of technological advancement, optimal effort, and revenue generation for both sectors. In comparison with the Spin-Off and Spin-In modes, the Mix mode provides a sound and resilient context for technology transfer, which improves innovation and leads to better long-term outcomes. The simulation result is consistent with the theoretical analysis where the Mix mode not only promotes the technology advancement but also enhances the overall system performance. Moreover, the research shows that though both Spin-Off and Spin-In modes are beneficial, the effects are not as great as Spin-In Mix mode to achieve Pareto efficiency. From these findings, it is clear that for those policy makers and organizations seeking ways to improve industrial transfer and DUT formation, a greater emphasis on cooperation between military and civilian organizations may well hold the key to the creation of dramatically increased returns on technology and economic growth.

CRediT Author Statement

The author reviewed the results and approved the final version of the manuscript.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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There are no competing interests

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